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ABSTRACT

The mastery of a concept is quite important in learning science. In classroom situations, it is difficult to assess if students have attained mastery in the absence of some systematic evaluation of their understanding of the concept. With this in view, a scheme of concept analysis was developed in science and test items were written for each sub-concept. The topic selected was "classification" and 30 concepts, 10 in each of the biological, earth, and physical sciences were developed. Each concept was analyzed on selected criteria. These were named as (1) identifying the relevant, irrelevant, and critical attributes; (2) selecting supraordinate, coordinate, and subordinate concepts; (3) formulating a defintiion; and (4) listing examples and non-examples. (PS)

Working Paper No. 57

An Analysis of Selected Classificatory Science Concepts in Preparation for Writing Tests of Concept Attainment

Report from the Project on a Structure of Concept Attainment Abilities

Wisconsin Research and Development
CENTER FOR COGNITIVE LEARNING

THE UNIVERSITY OF WISCONSIN
Madison, Wisconsin

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AN ANALYSIS OF SELECTED CLASSIFICATORY SCIENCE CONCEPTS IN PREPARATION FOR WRITING TESTS OF CONCEPT ATTAINMENT

By Alan M. Voelker, Juanita S. Sorenson
and Dorothy A. Frayer

Report from the Project on
A Structure of Concept Attainment Abilities
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STATEMENT OF FOCUS

The Wisconsin Research and Development Center for Cognitive Learning focuses on contributing to a better understanding of cognitive learning by children and youth and to the improvement of related educational practices. The strategy for research and development is comprehensive. It includes basic research to generate new knowledge about the conditions and processes of learning and about the processes of instruction, and the subsequent development of research-based instructional materials, many of which are designed for use by teachers and others for use by students. These materials are tested and refined in school settings. Throughout these operations behavioral scientists, curriculum experts, academic scholars, and school people interact, insuring that the results of Center activities are based soundly on knowledge of subject matter and cognitive learning and that they are applied to the improvement of educational practice.

This Working Paper is from the Project on the Structure of Concept Attainment Abilities in Program 1. It is the result of a cooperative effort among the staffs from the Concept Attainment project, Project 203--Elementary Science--in Program 2 and the Technical Development Program. Staffs from the Concept Attainment project and Project 203 identified the basic concepts in science at intermediate grade levels and Project 203 staff and staff from the Technical Development Program analyzed the concepts in preparation for developing tests to measure the level of concept mastery. Concept analyses will be used in the preparation of developmental materials in Project 203. The ensuing tests will be used to facilitate basic and development-based research in Project 203 and to study the relationships among cognitive abilities and learned concepts in various subject matter areas. The outcome of the Concept Attainment project will be a formulation of a model of structure of abilities in concept attainment in a number of subjects, including mathematics, language arts, and social studies, as well as science.

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The work of Professor Herbert J. Klausmeier and Dr. Dorothy A. Frayer also deserves recognition. Their research and development efforts related to the analysis of a concept and the measurement of concept attainment have resulted in the development and refinement of the concept analysis procedure employed in this study.

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ABSTRACT

A total of 30 classificatory science concepts, 10 each from the areas of the biological, earth, and physical sciences were selected and analyzed to provide a framework for preparing items to be used in testing a schema for measuring the level of concept mastery. The analysis of each concept consisted of identifying the relevant, irrelevant, and criterial attributes, selecting supraordinate, coordinate, and subordinate concepts, formulating a definition, and listing examples and non-examples.

I

INTRODUCTION

A major outcome, if not the major outcome, of the scientific enterprise is the generation of concepts of various types; science is a concept-forming activity of mankind. In their attempt to impose order on the universe, scientists devote their energies to three types of concept forming endeavors--classifying, relating and/or correlating, and theorizing.

The assessment of science concept learning has been and continues to be a major instructional problem due to lack of a system for measurement of concept attainment. An area in which this deficiency becomes of paramount concern is classroom achievement. For example, what levels of concept mastery have been attained by children or are attainable by children? Answers to these questions have relevance to the determination and specification of reasonable expectations for learning outcomes for school age children. Answers to these questions also have implications for the management of instruction; i.e., whether instructional sequences are designed for individuals, small groups, or large groups. The lack of a system for measurement of levels of concept attainment tends to hinder progress in the study of science concept learning.

Another major problem facing those concerned with concept learning in science is the formulation of a model of science concept attainment. A search for such a model has been and continues to be a common goal of the Center and of the science project. Thus, it is imperative that those concerned with the measurement of science concept learning address themselves to developing a model for science concept learning.

RELATED STUDIES

Two groups of studies conducted by the science project are directly related to the aforementioned problems. Studies conducted by Stauss (1968), Helgeson (1968), and Carey (1968) were concerned with determining elementary school children's level of attainment of science concepts of a classificational, correlational, or theoretical nature. The system employed for assessing levels of concept attainment was derived from Bloom's Taxonomy (1956). Test items were developed to determine students' concept attainment at the knowledge, comprehension, and application levels.

Some success in measuring levels of concept attainment was achieved, but with this particular system, specific tasks that children could perform were not always easily identifiable. The notion of general categories of learning was appropriate but the lack of specified tasks produced problems, even within the system. For example, children often achieved higher scores at the application level than at the comprehension level even though it is assumed that the comprehension level is a lower level of learning. In the absence of specified tasks it was difficult

to ascertain why a reversal of this type might have taken place. A second problem was the absence of common tasks across concepts. With the absence of a common system for measuring levels of concept attainment across concepts and classes of concepts, it was not possible to hypothesize a model for science concept learning. The third problem was that each study dealt with a concept from a different category: cell--a classificational concept, force--a correlational concept, and ion--a theoretical concept.

A second type of study conducted by Voelker (1968) attempted to determine the level of concept mastery of the classificational concepts physical and chemical change by children in Grades 2 through 6. Specific verbal and non-verbal tasks were devised for determining children's attainment of these concepts. The competencies the children were expected to attain were:

1. given the name of the concept, explain what the term means;
2. given the name (or names) of the concept, identify the ultimate criterion for classifying or identifying examples of the concept;
3. given the name of the concept, be able to distinguish between examples and non-examples of the concept;
4. given a particular natural phenomenon, be able to explain why it is an example or non-example of a concept; and
5. given a classificatory problem, ask questions to acquire additional information to facilitate the classification of the examples--a form of problem solving.

Tasks that the children were expected to perform were selected to determine whether there might some type of hierarchy in science concept learning and whether both verbal and non-verbal measures should be employed in assessment of concept attainment.

The latter study is more closely aligned with the study to be described. The tasks were devised to measure the attainment of specified competencies and to elicit several measures of the formation of a limited number of concepts. Studies of this nature might lead to the development of categories of science concepts and to determination of the type of tasks elementary school children can be expected to perform related to particular science concepts or classes of science concepts.

To date, the science project has not employed a common system for measurement of concept attainment. The intent has been to sample several techniques for measuring concept attainment so that through a series of approximations a common usable system might be developed.

A SCHEMA FOR TESTING THE LEVEL OF CONCEPT MASTERY

During the time the aforementioned studies were being conducted by the science group, the staff of the Project on Situational Variables and the Efficiency of Concept Learning was developing a system for measuring the level of concept mastery. A schema for testing the level of concept mastery evolved from a logical analysis of the nature of a concept, a review of the literature on cognitive processes in cognitive learning, adaptation of testing procedures used in previous

concept learning studies and development of new procedures (Frayer, Fredrick, & Klausmeier, 1969). Of the 13 tasks in the original list, 12 are of importance to this study. They are:

1. Given the name of an attribute, select an example of the attribute.
2. Given the example of an attribute, select the name of the attribute.
3. Given the name of a concept, select an example of the concept.
4. Given the name of a concept, select a non-example of the concept.
5. Given example of a concept, select the name of the concept.
6. Given the name of a concept, select a relevant attribute.
7. Given the name of a concept, select an irrelevant attribute.
8. Given the meaning of a concept, select the name of the concept.
9. Given the name of a concept, select the meaning of the concept.
10. Given the name of a concept, select the supraordinate concept.
11. Given the name of a concept, select the subordinate concept.
12. Given two concepts, select a principle relating them.

Stated properties of this schema are (1) it tests both verbal and nonverbal aspects of concept learning, (2) it permits differentiation of various levels or aspects of concept mastery, and (3) it is applicable to various types of concepts.

IMPLICATIONS FOR SCIENCE TEACHING

In examining the schema for testing the level of concept mastery, several questions come to mind. Some are of special interest to the concept attainment abilities group and others are more pertinent to the science group. Questions of the latter nature are:

1. Is the schema applicable to more than one class of science concepts, if so, which ones and to what degree?
2. What is the nature of those concepts to which the schema is not applicable?
3. Of the 12 tasks cited as measures of concept attainment, which tasks can children in elementary school perform related to classes of science concepts?
4. Can the schema be utilized to identify a concept hierarchy within the disciplines of science which can serve as a guide to measuring concept attainment and selecting concepts for an elementary school science program?
5. If the schema is not generally applicable to science concepts, what parts of it are usable to the science group?
6. How might the system be modified and/or adapted for use in testing the level of concept mastery in the sciences?
7. Can the students demonstrate concept mastery both verbally and non-verbally?

There are several possible benefits to be derived from investigations of the applicability of the schema for testing the level of concept mastery to science.

1. Identification of classificatory concepts and, ultimately, determination of the proportion of science concepts which are of this type. For example, it is likely that there are more classificatory concepts in the biological science area than in the physical science area.

2. Development of a system for evaluating learning outcomes. It may be possible to determine what general levels of concept mastery children can attain or what levels of concept attainment children can achieve for classificatory concepts. It may be possible to determine the kinds of tasks that children in the elementary school can attain in regard to classificatory concepts which would then in turn permit a basis for the development of instructional programs in self-contained classrooms or in non-graded, individually guided education.
3. Contribution to general learning theory. Are there models of concept formation that are common to all disciplines such as science, mathematics, and social studies?
4. Determination of a basis for defining science concepts.
5. Development of an item pool so that those people who have previously derived expectations for learning outcomes might have a source of valid and reliable items. Items of this type might be used to evaluate learning outcomes. Specifically, they might be used in pre-assessment situations to determine the levels of concept attainment which children have attained and allow program planners to organize science curricula according to reasonable expectations.

There should be a concern for structuring science curricula in the elementary school from the standpoint of cognitive development,

cognitive style, and ability as well as from the standpoint of the logical structure of the discipline. Implied in this statement is that it may be possible to relate classes of science concepts to learning abilities in planning a science curriculum indigenous to the local school system or school building, as the case may be.

It is the purpose of this paper, then, to describe the procedures employed in selecting and analyzing concepts to be used in preparing test items for investigating the level of attainment of selected science concepts by children in the intermediate grades. An attempt to alleviate some of the previously described problems is accomplished by limiting the concepts selected to one class and measuring children's attainment of similar tasks for each concept.

II

CONCEPT SELECTION PROCEDURES

TARGET POPULATION

The concepts selected and analyzed in preparation for writing test items to measure children's level of mastery are those commonly taught in the elementary grades at the intermediate grade levels. No specific group of children, as designated by grade level or other specific characteristics, was selected as the target population because the necessity of considering individual differences and minimizing testing difficulties due to reading inadequacies was recognized.

POTENTIAL TOPICAL AREAS

A basic prerequisite to selecting and analyzing the concepts was to select concepts which represent major topical areas pertinent to the subject-matter discipline. Three such organizational patterns were considered.

1. If the primary concern of science instruction in the elementary school were to produce a scientifically literate citizenry, it would be appropriate to select topical areas that are representative of the characteristics of a scientifically literate person. A scientifically

literate citizen has been characterized as one who possesses some understanding of

a. the interrelationships between science and society,
b. the ethics of science,
c. the nature of science,
d. the conceptual knowledge of science,
e. the difference between science and technology, and
f. the interrelationships between science and the humanities (Pella, O'Hearn, & Stiles, 1966).

This system is little used on the current scene in elementary school science curriculum.

2. Within the overall framework of scientific literacy, science is often considered to have a process aspect (the nature of science--observation, inference, model-building, decision-making, etc.), and a product aspect (the conceptual knowledge of science--facts, concepts, principles, etc.). Much emphasis is currently being given to organizing science curricula in the elementary school around one or the other poles of this artificial dichotomy; essentially, representing two aspects (c and d) of scientific literacy.
3. A second commonly employed framework for developing science curricula and materials for use in elementary school science programs focuses primarily upon the conceptual knowledge aspect of scientific literacy. When utilizing this criterion for examination of the nature of the

scientific enterprise, scientific products are generated in the areas of the biological sciences, the earth sciences, and the physical sciences.

SELECTION OF TOPICAL AREAS

The names of the science textbook series used in the elementary schools of Madison, Wisconsin, were obtained from the science supervisor for the Madison Public Schools.[1] It was learned that the Madison system had placed four textbook series on a basic adoption list and two textbook series on a supplementary resources list. All series were available to teachers. The two books on the supplementary list were not as generally available as those on the basic list, but the science supervisor indicated that they would probably be on the adoption list in future years. (See Appendix A.)

Preliminary study of the six series indicated that the content consisted largely of the nature of science (process aspects) and conceptual knowledge (product aspects). The remaining four referents for scientific literacy were almost totally excluded from consideration. In addition, the nature of science received only token visibility when compared to conceptual knowledge. It was on the basis of this examination that the decision was made to utilize alternative three, selecting

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[1] Science materials used in the Madison Public Schools were selected as the source of concepts because the studies concerning science concept attainment and related factors such as cognitive abilities are to be conducted with students from the Madison Schools.

concepts from the areas of biological, earth, and physical science as the framework for concept identification and selection. This system is satisfactory for discussing the product outcomes of the scientific enterprise and for testing for the level of concept mastery. Its weakness lies in the fact that only concepts from one referent to scientific literacy will be included in the study. However, it must be noted that the textbook is a dominant factor in determining the nature of the elementary school science program. If the level of concept mastery is related to instruction in a school environment, concepts need to be selected from the "existent" curriculum.

SELECTION OF CONCEPTS

It was previously stated that concepts in science may be classified as classificational, correlational, or theoretical. For the purpose of this study only classificatory (classificational) concepts were selected.

A classificatory concept is defined as one possessing three characteristics

1. There is more than one example of the concept.
2. The properties (attributes) of the concept can be described.
3. The concept can be labeled (named) by a word or a compound word.

A concept such as MARS would be an "identity" rather than a "classificational" concept because there is only one example. (It is assumed that children involved in the study will be familiar with the labels of the selected concepts

and further it is inferred that the children will be able to identify one or two positive examples.)

A survey of each of the six Grade 4 texts previously referred to was undertaken. Science concepts within each of the three topical areas--biological science, earth science, and physical science--that could be labeled with one or two words were identified as being present or not present in one or more of these six texts. The following guidelines were employed in the initial concept selection. Ideally, the concept label should appear in the printed material and there should be some basis for the development of the concept within the confines of the text. In those instances where a concept label appeared but the development of the concept was minimal, the Grade 3 text in the same series was examined. If the concept was well developed in the Grade 3 text, it was included on the list. In other instances a concept was well developed within the printed material, but the concept label was not explicitly stated. These concepts were also included on the list, based on the assumption that the teacher would have provided the label for the children or they would have acquired it from another source.

In order to increase the likelihood of a particular concept having been encountered by children in a given elementary school, it was decided that only those concepts which appeared in at least three of the four basic texts would be retained on the master concept list. This decision was necessary because of a lack of uniformity in the organization of the textbook series and each teacher having the prerogative of selecting the text(s) that he or she would want to

use. (Many teachers apparently prefer the multiple-text organization.) The list of concepts resulting from this analysis was subdivided into lists of biological science, earth science, and physical science concepts. Ten concepts were randomly selected from each of these three lists producing a set of 30 concepts which were subjected to a concept analysis. These 30 concepts are listed in Table 1.

Table 1

Biological, Earth, and Physical Science Concepts Subjected to Initial Concept Analysis

Earth Science	Biological Science	Physical Science
Sedimentary rock	Water	Solid
Volcano	Mammal	Liquid
Fossil	Fish	Thermometer
Glacier	Invertebrate	Temperature
Core (Earth)	Cell	Conductor
Wind	Muscle	Force
Planet	Survival	Matter
Moon	Environment	Molecule
Meteor	Lungs	Evaporation
Cloud	Plant	Melting

III

CONCEPT ANALYSIS

THE FUNCTION OF CONCEPT ANALYSIS

In preparation for constructing test items designed to measure children's level of concept attainment or preparing instructional sequences designed to teach concepts to children, it is necessary to analyze the concepts so that a framework is available for making decisions about which elements of the concept are to be measured (are measurable).

Each of the 30 concepts, 10 per science area, was analyzed by the item writer, a science education specialist, and the principal investigator for science. The results of these analyses made the following information available for use in writing items.

1. A list of attributes--criterial, relevant, and irrelevant.
2. Supraordinate, coordinate, and subordinate concepts.
3. A definition.
4. Examples and non-examples.
5. Relationships involving 2 concepts.

CONCEPT ANALYSIS PROCEDURES

Concepts, especially classificatory concepts, can be described or analyzed in terms of their characteristics and/or properties, otherwise

known as attributes. Some of these attributes are common to every instance of the concept while others are characteristic of only some instances of the concept. Those attributes which are properties of every instance of the concept are known as relevant attributes while those attributes characteristic of some, but not all, instances of the concept are known as irrelevant attributes.

The first task in completing the analysis of a concept was to identify the relevant and irrelevant attributes. An appropriate means of identifying these attributes is to think of as many examples of the concept as possible and discern what these examples have in common. Consider the concept MAMMAL. All mammals possess the properties (attributes) of being warm-blooded, having hair and feeding the young on the mother's milk. Each new example of mammal that is identified will also possess these attributes. These attributes which are characteristic of every example of the concept are called relevant attributes.

In addition to those attributes that are common to all examples of the concept there are attributes that are unique to a specific concept example or are shared by only some concept examples. Again, consider the concept MAMMAL. Many, but not all, mammals live on land. Many, but not all, mammals have four legs. These attributes are characteristic of some, but not all, examples of the concept and thus are known as irrelevant attributes.

Following the identification of relevant and irrelevant attributes for a concept, supraordinate, coordinate, and subordinate concepts are

identified. The supraordinate of a concept is more general or inclusive than the concept whereas the subordinate is less inclusive or more specific.

A supraordinate concept is one which has some, but not all, of the relevant attributes of a given concept. The concept VERTEBRATE is immediately supraordinate to the concept MAMMAL. Vertebrates include all animals which have a backbone. Because all mammals have a backbone, VERTEBRATE is supraordinate to MAMMAL. Vertebrate is more inclusive than mammal, however, because it includes all other animals with backbones such as fish, amphibians, reptiles, and birds.

Concepts which are coordinate to the concept MAMMAL are FISH, BIRDS, REPTILES, and AMPHIBIANS. These concepts, like MAMMAL, are examples of the concept VERTEBRATE because they share the common attribute of possessing a backbone but they differ among one another in many ways. For example, mammals and birds are both examples of vertebrates and are warm-blooded, but all mammals have hair while all birds are covered with feathers. Therefore, coordinate concepts have the same supraordinate concept but different criterial attributes than the target concept. Having hair is relevant to mammals but not to birds while being covered with feathers is relevant to birds but not to mammals.

Concepts which are subordinate to MAMMAL include DOG, CAT, SQUIRREL, LION, and RABBIT. These concepts possess all the relevant attributes of the concept MAMMAL--i.e., they are warm-blooded, have hair, and feed the young on mother's milk--but each has other relevant attributes in addition.

Once the relevant and irrelevant attributes and the supraordinate, coordinate, and subordinate concepts were identified, criterial attributes were selected. These criterial attributes identify the given concept within the selected supraordinate concept (or from coordinate concepts if a supraordinate could not be identified). Examine the concepts MAMMAL, BIRD, FISH, REPTILE, and AMPHIBIAN. Each of these five concepts is an example of the supraordinate concept VERTEBRATE and are coordinate to each other. Thus, there must be attributes which permit MAMMAL to be distinguished from its coordinate concepts. There are three revelant attributes for the concept MAMMAL but only two of these are criterial. Only mammals have hair and feed their young on the mother's milk. The third relevant attribute--warm-blooded--is also a relevant attribute of the concept BIRD and, therefore, cannot be criterial to the concept MAMMAL. Those attributes which are criterial to the concept MAMMAL are not possessed by any of its coordinate concepts; i.e., they can be employed to distinguish mammals from the other subordinates of the concept VERTEBRATE--BIRDS, REPTILES, FISH, and AMPHIBIANS.

A definition was then formulated which included the name of the supraordinate concept and the criterial attributes. In those instances where there was no supraordinate concept the definition contains only the criterial attributes. In the case of the concept MAMMAL the definition would be as follows: A mammal is a warm-blooded vertebrate animal that has hair and feeds its young on the mother's milk.

The next step in the analysis procedure was to prepare lists of examples and non-examples of the concept.

The final step in the analysis consisted of indicating how the given concept was related to at least one other concept. This relationship was preferably a principle. Direct supraordinate-subordinate relationships, relationships involving criterial attributes, and relationships involving examples were not used. In the case of MAMMAL, for example, an appropriate relationship could be expressed between this concept and the concept LUNG--mammals use lungs for breathing.

AN ANALOGY

The concept analysis procedure can be likened to using classification rules to distinguish one class of objects or things from another class and to differentiate among members of a given class. Figure 1 illustrates the taxonomic breakdown for living things.

Living things are divided into the two groups, plants and animals. The animals are in turn divided into two groups called vertebrates and invertebrates. Vertebrates are further divided into five groups: amphibians, birds, fish, mammals, and reptiles. The mammals are further divided into several groups including dogs, cats, whales, and the like. A concept analysis, then, is essentially listing the properties and characteristics (attributes) of a concept. These attributes are then designated as relevant, irrelevant, or criterial, depending on whether the attribute is common to some or all examples of a concept or whether it can be utilized to differentiate the concept from its coordinates.

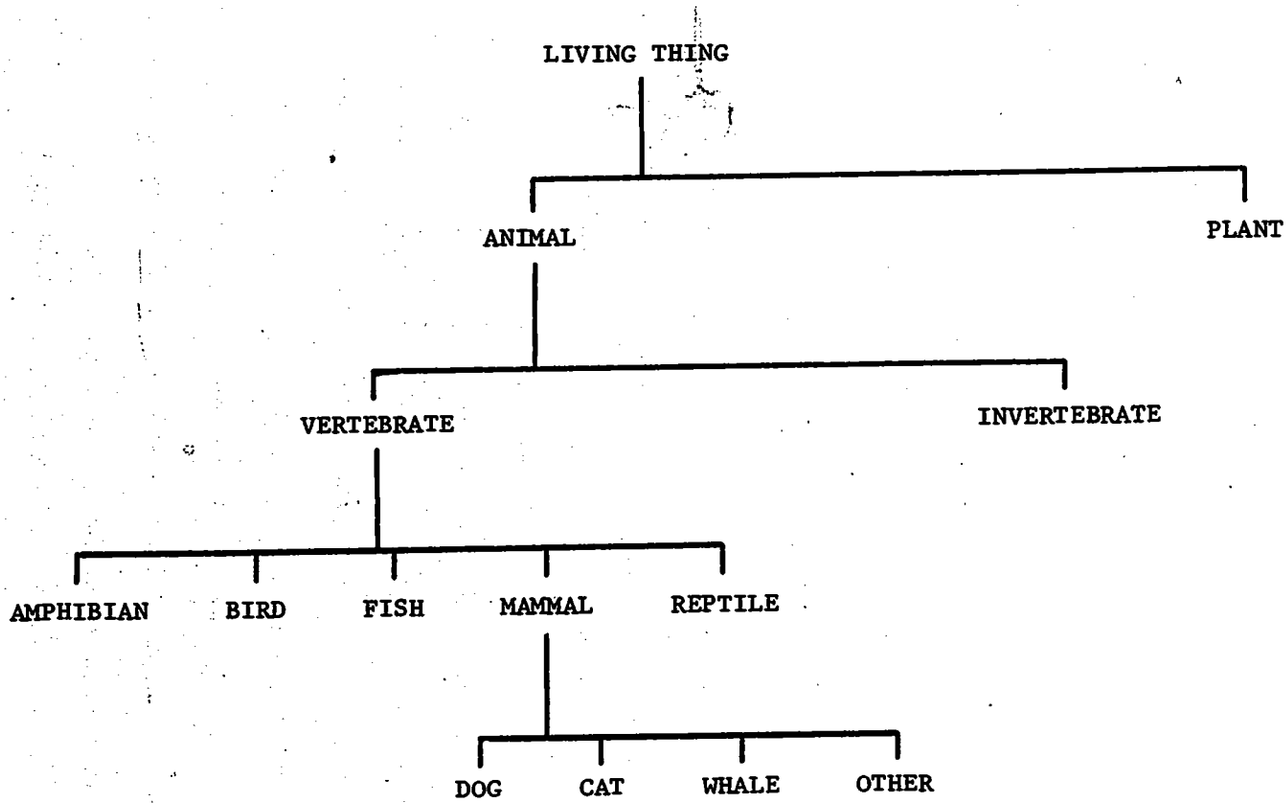

Figure 1. A taxonomic hierarchy of living things.

The level at which a concept is located in the hierarchy will determine whether it has supraordinate or subordinate concepts. MAMMAL has several supraordinate concepts (VERTEBRATE, ANIMAL, LIVING THING), several coordinate concepts (BIRD, FISH, REPTILE, AMPHIBIAN), and several subordinate concepts (DOG, CAT, WHALE, HORSE).

An explanation or definition of each of the types of information produced during the analysis of a concept follows.

A SUPRAORDINATE CONCEPT is one which has some but not all of the relevant attribute values of the given concept.

A COORDINATE CONCEPT has the same supraordinate concept but differs in the particular attribute values which are relevant.

A SUBORDINATE CONCEPT has all of the relevant attribute values of the given concept and others in addition.

CRITERIAL ATTRIBUTES identify the concept within the selected supraordinate concept and differentiate among the coordinate concepts.

OTHER RELEVANT ATTRIBUTES are relevant but not criterial.

IRRELEVANT ATTRIBUTES vary among instances of the concept.

A DEFINITION of a concept includes the name of the supraordinate concept and the criterial attributes. In instances where there is no supraordinate concept, the definition includes all relevant attributes of the concept.

CONCEPT EXAMPLES. Positive examples of the given concept.

CONCEPT NON-EXAMPLES. Those which are not examples of the given concept.

In conducting the analysis of a concept all attributes, examples, non-examples, and the definition were stated in terms that fifth grade children can purportedly read and understand.[2] A concept which fit the definition of classificatory concept and which could be completely analyzed according to the described system was retained for the item construction phase of the study. A concept which did not meet both of these criteria was omitted at this point and a new concept was randomly selected to replace it. Concepts from the original lists (Table 1) which did not meet one or the other of these criteria are listed in Table 2.

Those concepts which fit the definition of classificatory concept, for which it was possible to complete the concept analysis, and for which appropriate items could be constructed are listed in Table 3.

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[2] In some instances there will be an inconsistency between a definition acceptable to the scholars in the discipline and the definition commonly taught and tested in the elementary school. These instances are noted on the concept analyses sheets. Where this discrepancy existed, the procedures called for testing the definition appropriate to the elementary school child.

Table 2

Concepts Not Meeting Definitional or Analysis Criteria

Biological Science	Earth Science	Physical Science
Environment	None	Force
Plant		Matter
Survival		Temperature
Water		

Table 3

Concepts for Which Tests of Concept Mastery Were Written

Biological Science	Earth Science	Physical Science
Bird	Cloud	Conductor
Cell	Core (Earth)	Evaporation
Fish	Fossil	Expansion
Heart	Glacier	Friction
Invertebrate	Meteor	Liquid
Lens (Eye)	Moon	Melting
Lungs	Planet	Molecules
Mammal	Sedimentary Rock	Solid
Muscle	Volcano	Sound
Pore	Wind	Thermometer

SAMPLE ANALYSES

The results of the analysis for one concept from each of the three areas--biological, earth, and physical science--follow. Analyses of all 30 concepts are presented in Appendix B.

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: MAMMAL

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

A mammal is a warm-blooded vertebrate animal that has hair and feeds its young on the mother's milk.

(Definition Tested: A mammal is a warm-blooded animal which feeds its young on the mother's milk.)

Supraordinate Concept(s): vertebrate, animal

Coordinate Concept(s): fish, reptile, bird, amphibian

Subordinate Concepts(s): dog, cat, squirrel, lion, rabbit

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Mammals:

1. feed their young on the mother's milk
2. have hair

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to mammal are those of its supra-ordinates, vertebrates and warm-blooded animals, such as:

1. having a backbone (vertebrate)
2. maintaining a constant body temperature (warm-blooded animals)

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of mammal include:

1. color: black, brown, yellow
2. pattern of coat: plain, striped, spotted
3. habitat: lives on land, lives in water
4. eating habits: eats other animals, eats plants

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Mammals use lungs for breathing.

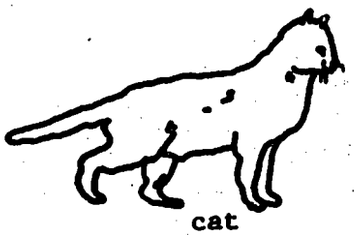
Concept examples include the following:

dog, cat, squirrel, rabbit, horse, cow, camel

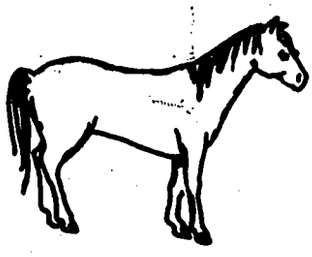
Pictorial examples:

camel

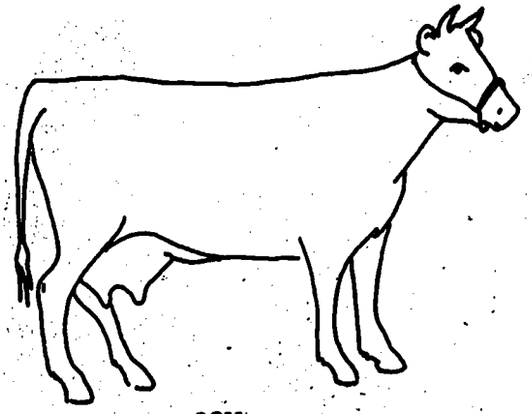
dog



cat



horse



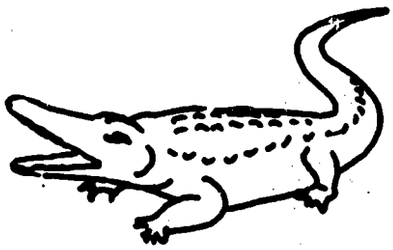
cow

Concept non-examples include the following:

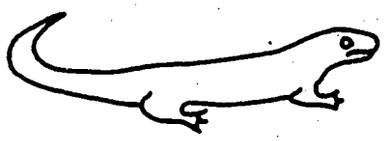
frog, alligator, chicken, snake, salamander

Pictorial non-examples:

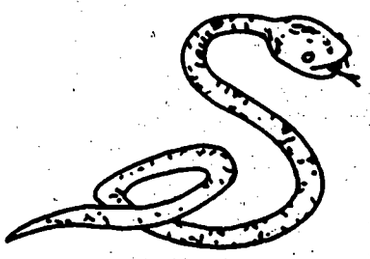
frog



alligator



salamander



snake

chicken

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: PLANET

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

A planet is a heavenly body which revolves around the sun and shines by reflected light.

Supraordinate Concept(s): heavenly body, solar system

Coordinate Concept(s): moon, meteor

Subordinate Concepts(s): major or minor

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Planets:

1. revolve around the sun

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Relevant attributes of planet include:

1. shining by reflected light

Other attributes relevant to planet are those of its supra-ordinates, heavenly body and solar system, such as:

1. being located in space
2. having their motion affected by other heavenly bodies

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of planet include:

1. visibility to the naked eye
2. temperature of the planet's surface
3. apparent color (to the earthly observer)
4. existence of life on planet

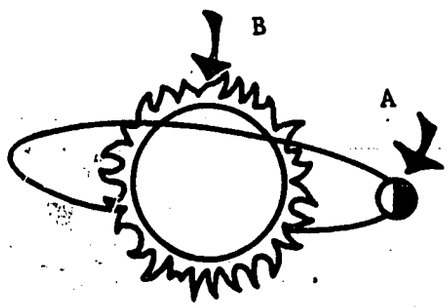
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Planets travel in paths called orbits.

Concept examples include the following:

planet

Pictorial examples:

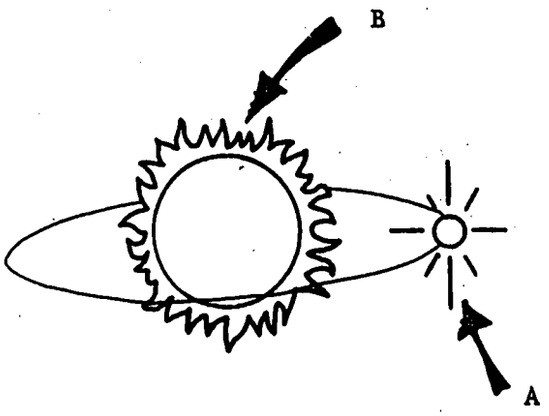


A. planet
B. sun

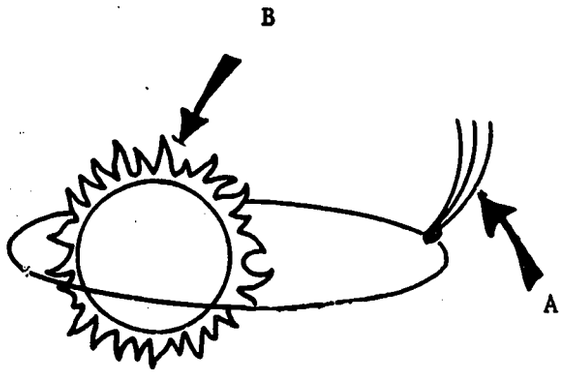
Concept non-examples include the following:

sun, star, meteor, comet, moon

Pictorial non-examples:



A. star
B. sun



A. comet
B. sun

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: SOLID

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A solid is a form of matter which has both a definite (exact) shape and a definite (exact) volume.

Supraordinate Concept(s): matter

Coordinate Concept(s): gas, liquid

Subordinate Concepts(s): table, rock, pan, chair

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Solids have:
1. a definite shape

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Relevant attributes of solid include:
1. having a definite volume

Other attributes relevant to solid are those of its supraordinate, matter, such as:
1. having weight
2. occupying space
3. being made up of particles which are always in motion

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of solid include:
1. color
2. size
3. texture
4. shape

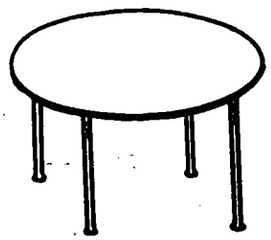
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

When a solid changes to a liquid, it is called melting.

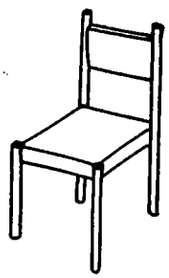
Concept examples include the following:

top, chair, table, rock

Pictorial examples:



table



chair

top

rock

Concept non-examples include the following:

all liquids and all gases

Pictorial non-examples:*

liquid

liquid

liquid

*Since gases are difficult to depict in line drawings, only examples of liquids are shown.

IV

ITEM PREPARATION

THE SCHEMA

The third phase in preparing for the study was to construct a Concept Mastery Test for each of the 30 concepts. Each test consisted of 12 items, each item corresponding to one of the 12 tasks of the Schema for Testing the Level of Concept Mastery (Frayer, et al., 1969).

A brief description of the nature of the items for each concept test follows.

Items No. 1 and 2 require the children to associate the name of a concept attribute with an example of a concept attribute.

Items No. 3, 4, and 5 require the children to associate the name of the concept with examples and non-examples of the concept.

Item No. 6 requires the children to associate the name of the concept with a relevant attribute and Item No. 7 requires the children to associate the name of the concept with an irrelevant attribute.

Item No. 8 requires the children to associate the concept label with the concept definition whereas Item No. 9 requires the children to select the definition which fits the concept label.

Items No. 10 and 11 require the children to identify a supraordinate (#10) and a subordinate concept (#11) of the target concept.

Item No. 12 requires the children to identify a relationship between the target concept and another concept. (In as many instances as possible this relationship was a principle.)

ITEM CONSTRUCTION PROCEDURES

One criterion for determining whether a concept was included in the study was whether it was possible to write an appropriate item for each of the 12 tasks of the schema. If not, a concept was eliminated and a new concept randomly selected to replace it.

An attempt was made to make each item a four-choice multiple response item. However, in those instances where it would be necessary to contrive an unrealistic response less than four responses were accepted. All items were written to approximate as closely as possible the language and reading level of fifth grade children.

Items were initially prepared by an item writer who was a science education specialist. These items were reviewed by the principal investigator, also a science education specialist, and then submitted to a group of graduate students in science education representing the areas of biological, earth, and physical science. When the items

met with the approval of all three of these reviewers they were subjected to further review by the staff of the Concept Attainment Abilities group. This group included experienced elementary teachers, a specialist in tests and measurement, and a specialist in concept learning. Modifications suggested by the latter group were considered by the item writer and the principal investigator in making item modifications. It was the function of these reviewers to give consideration to content validity of the items, whether the items met general criteria for construction of multiple response test items, whether the reading and language difficulty level was appropriate, and whether an item as written corresponded to the appropriate task of the schema.

ITEM TRYOUT

A pilot study was conducted with fifth-grade children to gather data to be utilized in revising items and improving test reliabilities prior to gathering data for the main study. A total of five 72-item tests was administered to every subject. Each test consisted of the 12 items for six of the 30 concepts. Items were randomly assigned to position on the tests.

ITEM REVISION

The original item writer, the principal investigator, and the project manager for the Concept Attainment Abilities Study conducted

the major portion of the item revision. Preliminary work was conducted by the item writer and principal investigator while final decisions were made in a session which included the item writer, the principal investigator, and the project manager.

The results of the item tryouts and the subsequent revised concept tests are reported in Working Paper No. 58: Items for Measuring the Level of Attainment of Selected Classificatory Science Concepts by Intermediate Grade Children (Voelker & Sorenson, 1971).

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Carey, R. L. Relationship between levels of maturity and levels of understanding of selected concepts of the particle nature of matter. Technical Report from the Wisconsin Research and Development Center for Cognitive Learning, The University of Wisconsin, 1968, No. 36.

Frayer, D. A., Fredrick, W. C., & Klausmeier, H. J. A schema for testing the level of concept mastery. Working Paper from the Wisconsin Research and Development Center for Cognitive Learning, The University of Wisconsin, 1969, No. 16.

Helgeson, S. L. The relationships between concepts of force attained and maturity as indicated by grade levels. Technical Report from the Wisconsin Research and Development Center for Cognitive Learning, The University of Wisconsin, 1968, No. 43.

Pella, M. O., O'Hearn, G. T., & Stiles, L. J. Scientific literacy in the aerospace age. Technical Report from the Scientific Literacy Research Center, The University of Wisconsin, 1966, No. 1.

Stauss, N. G. An investigation into the relationship between concept attainment and level of maturity. Technical Report from the Wisconsin Research and Development Center for Cognitive Learning, The University of Wisconsin, 1968, No. 40.

Voelker, A. M. The relative effectiveness of two methods of instruction in teaching the classificational concepts of physical and chemical change to elementary school children. Technical Report from the Wisconsin Research and Development Center for Cognitive Learning, The University of Wisconsin, 1968, No. 39.

Voelker, A. M., & Sorenson, J. S. Items for measuring the level of attainment of selected classificatory science concepts by intermediate grade children. Working Paper from the Wisconsin Research and Development Center for Cognitive Learning, The University of Wisconsin, 1971, No. 58.

APPENDIX A

SOURCE OF SCIENCE CONCEPTS

The science concepts for which tests of concept mastery were written were selected from a list of concepts obtained by analyzing the third- and fourth-grade texts from the following series.

*1. Blough, G. O., Marshall, J. S., Bailey, J. B., Beauchamp, W. L. Science is experimenting. Chicago: Scott, Foresman & Company, 1965.

**2. Brandwein, P. F., Cooper, E. K., Blackwood, P. E., & Hone, E. B. Concepts in science. New York: Harcourt, Brace & World, Inc., 1966.

*3. Jacobson, W. J., Lauby, C. J., & Konicek, R. D. Probing into science. New York: American Book Company, 1965.

**4. MacCracken, H. D., Brown, R. A., Decker, D. G., Kuse, H. R., Sund, R. B., & Trowbridge, L. W. Science through discovery. New York: The L. W. Singer Company, Inc., 1968.

*5. Mallinson, G. G., Mallinson, J. B., Steinberg, J. E., & Trexler, C. R. Science 4. Morristown, New Jersey: Silver Burdett Company, 1965.

*6. Navarra, J. G., & Zafforoni, J. Today's basic science 4. New York: Harper & Row, 1967.

*Basic
**Supplementary

APPENDIX B

ANALYSES OF THIRTY SCIENCE CONCEPTS

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: BIRD

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

Birds are warm-blooded animals which are covered with feathers; the female lays eggs.

Supraordinate Concept(s): animal, vertebrate

Coordinate Concept(s): mammal, reptile, amphibian, fish

Subordinate Concepts(s): cardinal, robin, sparrow, parakeet

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Birds:
1. are covered with feathers

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Relevant attributes of bird include:
1. the female laying eggs
2. being warm-blooded

Other attributes relevant to bird are those of its supraordinates, vertebrate and animal, such as:
1. having a backbone (vertebrate)
2. being living things (animals)

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of bird include:
1. size: small, large
2. color: red, blue, gray, brown
3. habitat: land, water
4. eating habits: insects, nectar, seeds

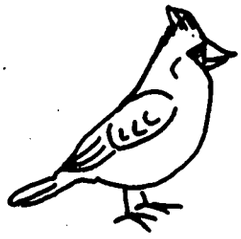
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely <u>not</u> be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

<u>Birds</u> use a <u>gizzard</u> to help digest food.

Concept examples include the following:

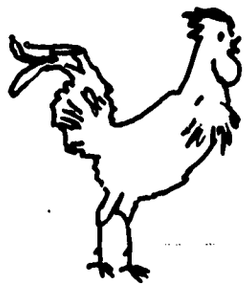
robin, sparrow, blackbird, canary, cardinal, flamingo, chicken

Pictorial examples:



cardinal

flamingo



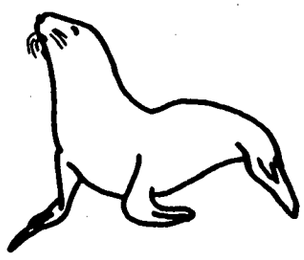
chicken

Concept non-examples include the following:

bat, seal, salamander, frog, dog, snake, alligator

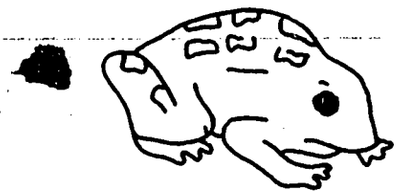
Pictorial non-examples:

bat



seal

salamander



frog

dog

57

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: CELL

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

The cell is the smallest unit of most living things.

Supraordinate Concept(s): basic unit

Coordinate Concept(s): --

Subordinate Concepts(s): blood cell, bone cell, nerve cell

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Cells are:
1. the smallest unit of most living things

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to cell are those of its supra-ordinate, basic unit.

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of cell include:
1. shape
2. size

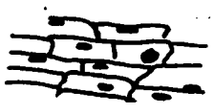
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Muscles are made up of a certain kind of cell.

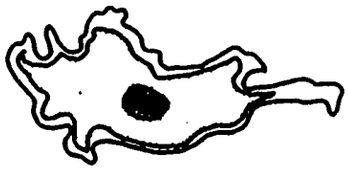
Concept examples include the following:

blood cell, nerve cell, onion cell, amoeba

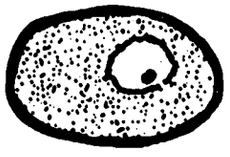
Pictorial examples:



onion cell



amoeba

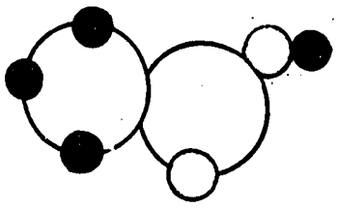


generalized cell

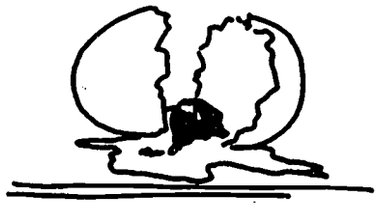
Concept non-examples include the following:

molecule, egg , eye

Pictorial non-examples:



molecule



egg

eye

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: FISH

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A fish is a cold-blooded animal that has fins and lives in water.

Supraordinate Concept(s): vertebrate, animal

Coordinate Concept(s): mammal, amphibian, reptile, bird

Subordinate Concepts(s): perch, trout, bass, goldfish

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Fish:
1. have fins

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Relevant attributes of fish include:
1. living in water

Other attributes relevant to fish are those of its supraordinates, vertebrate and cold-blooded animals, such as:
1. having a backbone (vertebrate)
2. taking the temperature of their surroundings (cold-blooded animal)

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of fish include:
1. color: gold, black, silver
2. size: large, small
3. shape: long and slim, short and stocky
4. eating habits: eat other fish, eat plants

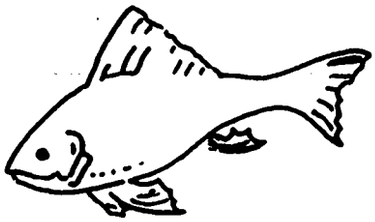
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Fish use gills for breathing.

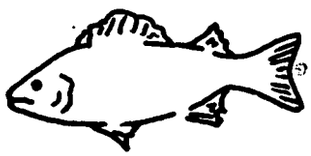
Concept examples include the following:

perch, trout, swordfish, sailfish, sturgeon

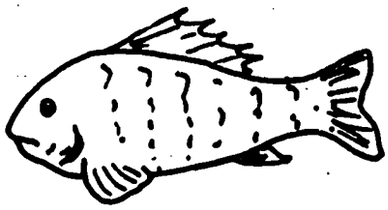
Pictorial examples:*



fish



fish



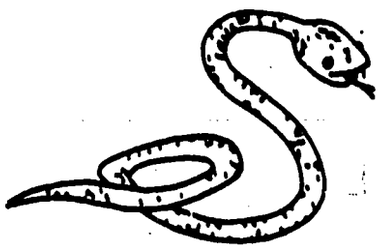
fish

*Differentiation between kinds of fish (e.g., between perch and trout) is difficult with line drawings. Therefore, no attempt has been made to identify the pictorial examples other than as fish.

Concept non-examples include the following:

seal, snake, cat, dog, rabbit, frog, alligator

Pictorial non-examples:

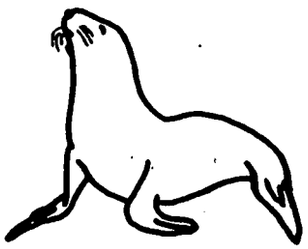


snake

cat

frog

alligator



seal

dog

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: HEART (human)

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

The heart (human) is an organ which pumps blood throughout the body.

Supraordinate Concept(s): organ

Coordinate Concept(s): lung, kidney, intestine, stomach

Subordinate Concepts(s): none

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

The heart:
1. pumps blood throughout the body

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to heart are those of its supra-ordinate, organ, such as:
1. being made up of a group of tissues working together to perform a specific function

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of heart include:
1. size
2. rate of pumping

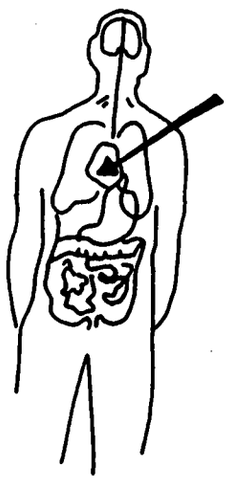
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

The heart pumps blood to the stomach.

Concept examples include the following:

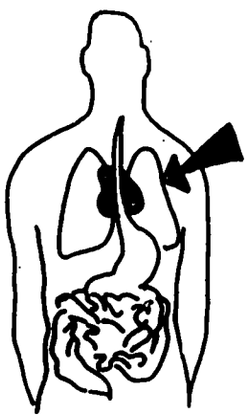
heart (human)

Pictorial examples:

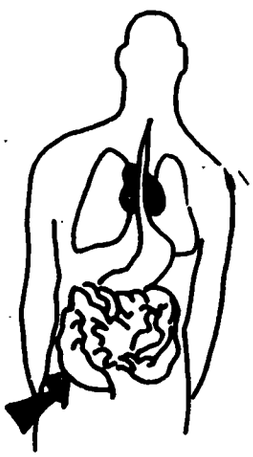


Concept non-examples include the following:

brain, kidney, stomach, lung, intestine



lung



intestine

stomach

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: INVERTEBRATE

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

Invertebrates are animals without backbones.

Supraordinate Concept(s): animal

Coordinate Concept(s): vertebrate

Subordinate Concepts(s): jellyfish, lobster, insect, spider

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Invertebrates have:
1. no backbone

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to invertebrate are those of its supra-ordinate, animal, such as:
1. being living things
2. being able to reproduce themselves

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of invertebrate are:
1. size
2. color
3. habitat
4. eating habits
5. number of appendages

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely <u>not</u> be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Most <u>invertebrates</u> do not have <u>lungs</u>.

Concept examples include the following:

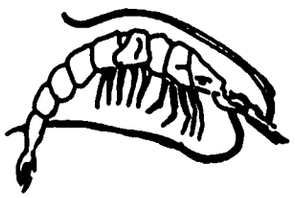
starfish, octopus, crayfish, insect, spider

Pictorial examples:

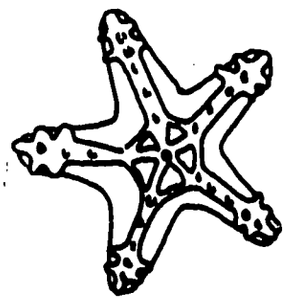
spider

octopus

insect



crayfish



starfish

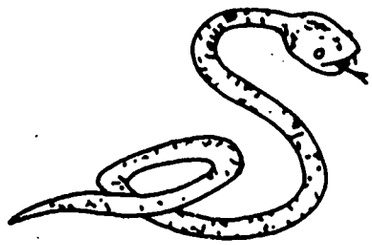
Concept non-examples include the following:

fish, reptiles, mammals, amphibians, birds

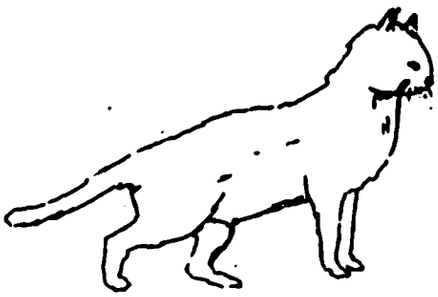
Pictorial non-examples:

amphibian

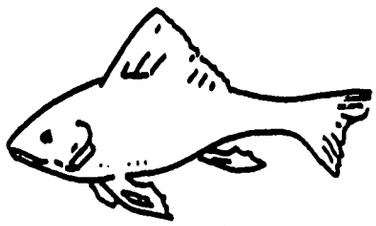
mammal



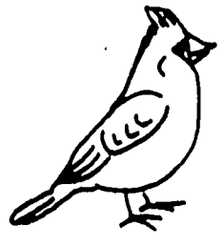
reptile



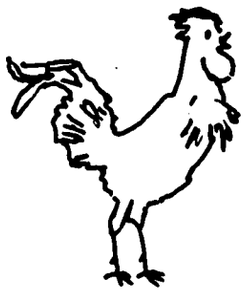
mammal



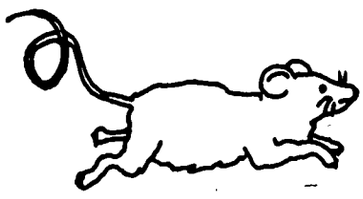
fish



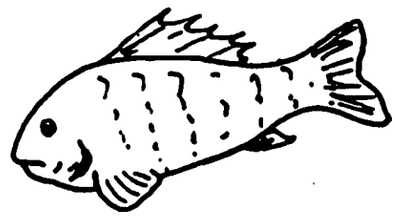
bird



bird



mammal



fish

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: LENS (of the eye)

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

> The lens is the eye part which bends or changes the direction of light rays and focuses them on the retina.

Supraordinate Concept(s): eye part

Coordinate Concept(s): cornea, retina, iris

Subordinate Concepts(s): convex lens, concave lens

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

The lens (of the eye):
1. bends light rays

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to lens (of the eye) are those of its supraordinate, eye part.

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of lens (of the eye) include:
1. t[redacted]ss
2. sh[redacted] of the image it produces

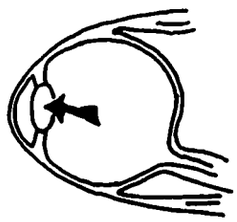
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

The iris controls the amount of light hitting the lens.

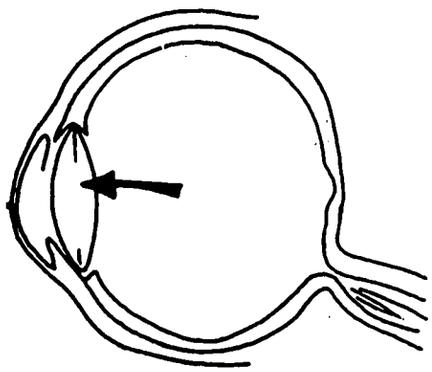
Concept examples include the following:

lens of the human eye

Pictorial examples:



lens of the eye

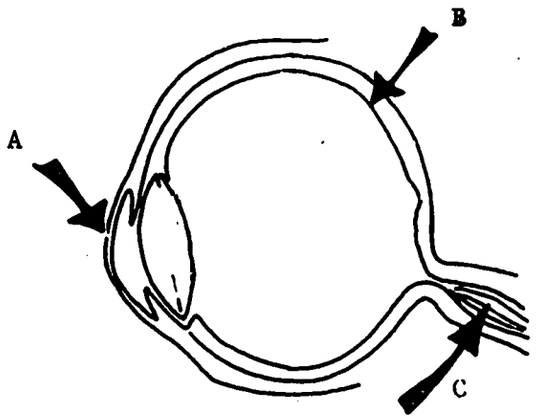


lens of the eye

Concept non-examples include the following:

iris, retina, cornea, optic nerve

Pictorial non-examples:



A. cornea
B. retina
C. optic nerve

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: LUNGS

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

> Lungs are the sac-like organs in the chest cavity of the body where carbon dioxide is exchanged for oxygen.

Supraordinate Concept(s): organ

Coordinate Concept(s): heart, stomach, kidney, intestine

Subordinate Concepts(s): --

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Lungs are:
1. a place for exchange of carbon dioxide and oxygen

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to lungs are those of its supra-ordinate, organ(s), such as:
1. a group of tissues working together to perform a specific function

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of lungs include:
1. size: large or small
2. condition: inflated or deflated
3. shape

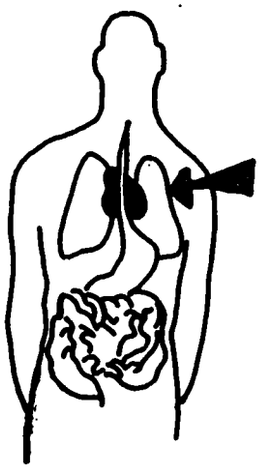
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

The lungs are protected by the ribs.

Concept examples include the following:

lung(s) human (This was the only mention of lungs at this grade level.)

Pictorial examples:



lung (s)

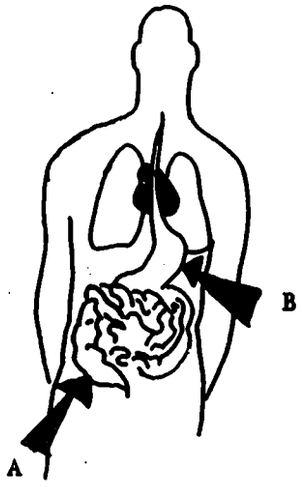
Concept non-examples include the following:

stomach, kidneys, heart, intestines, tonsils

Pictorial non-examples:

stomach

heart



A. intestines
B. stomach

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: MAMMAL

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A mammal is a warm-blooded animal that has hair and feeds its young on the mother's milk.

(Definition Tested: A mammal is a warm-blooded animal which feeds its young on the mother's milk.)

Supraordinate Concept(s): vertebrate, animal

Coordinate Concept(s): fish, reptile, bird, amphibian

Subordinate Concepts(s): dog, cat, squirrel, lion, rabbit

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Mammals:
1. feed their young on the mother's milk
2. have hair

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to mammal are those of its supraordinates, vertebrates and animals, such as:
1. having a backbone (vertebrate)
2. maintaining a constant body temperature (warm-blooded animals)

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of mammal include:
1. color: black, brown, yellow
2. pattern of coat: plain, striped, spotted
3. habitat: lives on land, lives in water
4. eating habits: eats other animals, eats plants

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Mammals use lungs for breathing.

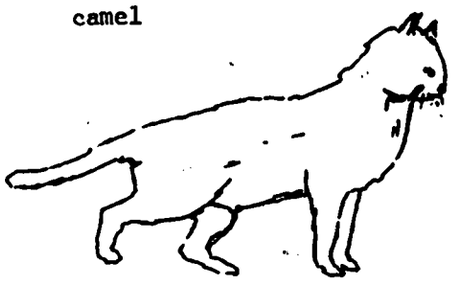
Concept examples include the following:

dog, cat, squirrel, rabbit, horse, cow, camel

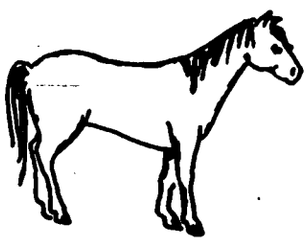
Pictorial examples:

dog

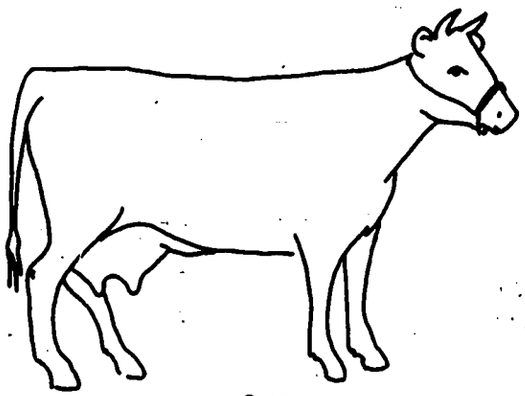
camel



cat



horse

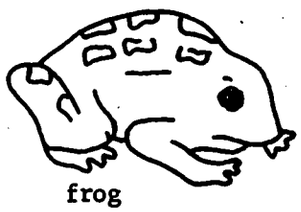


cow

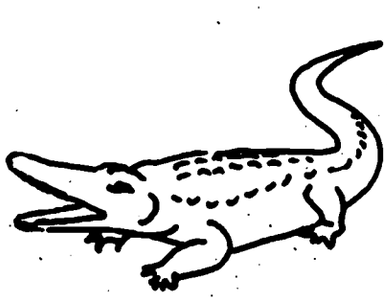
Concept non-examples include the following:

frog, alligator, chicken, snake, salamander

Pictorial non-examples:

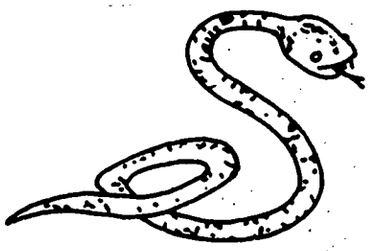


frog

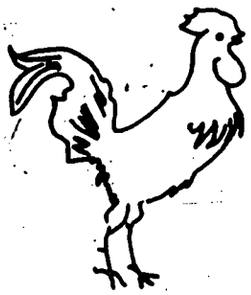


alligator

salamander



snake



chicken

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: MUSCLE

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

Muscles are organs which help move body parts by contracting and relaxing.

Supraordinate Concept(s): organ

Coordinate Concept(s): lung, heart, nerve, stomach, bone

Subordinate Concepts(s): voluntary muscle, involuntary muscle

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Muscles:

1. contract and relax
2. help move body parts

The combination of the two attributes above is necessary to identify muscle.

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to muscle are those of its supraordinate, organ, such as:

1. groups of tissues working together to perform a specific function

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of muscle include:

1. size: large or small
2. strength: strong or weak

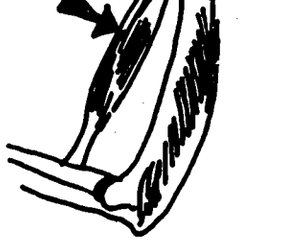
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

The heart is made of a certain kind of muscle.

Concept examples include the following:

arm muscles, leg muscles

Pictorial examples:



arm muscle

Concept non-examples include the following:

bones, joints, ligaments

Pictorial non-examples:

A. bone
B. joint

CONCEPT ANALYSES

Area: Biological Science

Target Concept Label: PORE (of the skin)

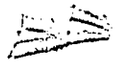
Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

A pore is a small opening in the skin through which sweat, wastes and other substances come out.

Supraordinate Concept(s): opening

Coordinate Concept(s): mouth, nostril, anus

Subordinate Concepts(s): none



Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Pores (of the skin):

1. are located in the skin
2. allow sweat and other wastes to come out through them

A combination of the two attributes above is necessary to identify pore.

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to pore (of the skin) are those of its supraordinate, opening.

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of pore (of the skin) include:

1. size
2. shape
3. whether or not wastes are coming out at a given time

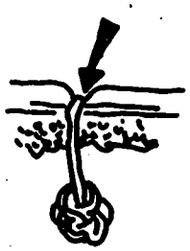
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Human beings eliminate wastes through pores.

Concept examples include the following:

typical skin pore (with gland and tube)

Pictorial example:



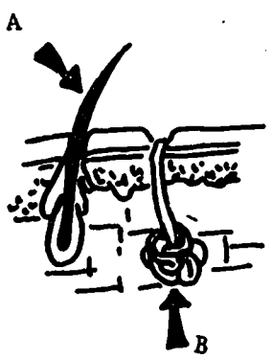
pore

92

Concept non-examples include the following:

hair, gland, tube between gland and pore

Pictorial non-examples:



A. hair
B. gland

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: CLOUD

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A cloud is a visible mass of water droplets or ice crystals above the earth's surface.

Supraordinate Concept(s): water

Coordinate Concept(s): visible mass of particulate matter

Subordinate Concepts(s): cumulus cloud, stratus cloud, cirrus cloud

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Clouds:

1. are visible masses of water droplets or ice crystals

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Attributes relevant to cloud include:

1. being located above the earth's surface

Other attributes relevant to cloud are those of its supraordinate, water, such as:

1. existing in more than one state of matter

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of cloud include:

1. thickness (density)
2. size
3. color
4. shape
5. altitude at which they occur

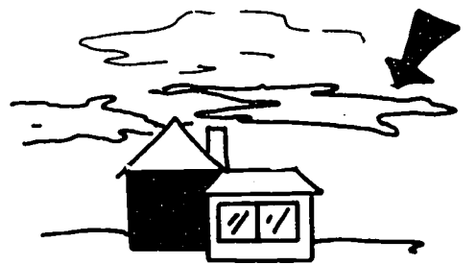
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Clouds are found in the earth's atmosphere.

Concept examples include the following:

cumulus, stratus, cirrus

Pictorial examples:



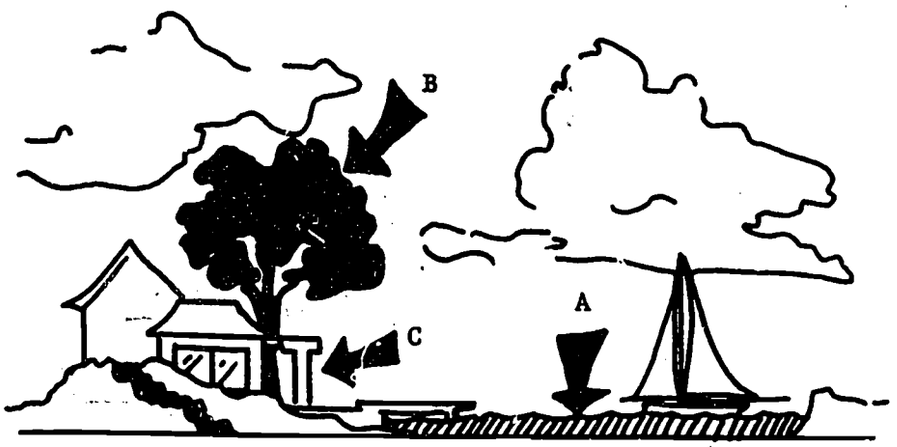
stratus

cumulus

Concept non-examples include the following:

clear sky, lake, tree, airplane, building

Pictorial non-examples:



A. lake
B. tree
C. building

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: CORE (of the earth)

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

The core of the earth is the center zone (the inner-most part).

Supraordinate Concept(s): zone

Coordinate Concept(s): mantle, crust

Subordinate Concepts(s): inner core, outer core

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

The core (of the earth):
1. is at the center

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to core (of the earth) are those of its supraordinate, zone, such as:
1. having a specific location
2. having identifiable limits

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of core (of the earth) include:
1. size of core

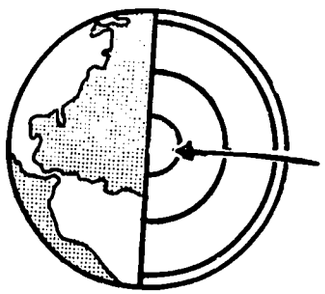
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

The core (of the earth) has a very high temperature.

Concept examples include the following:

map of the earth with an arrow to the center

Pictorial example:

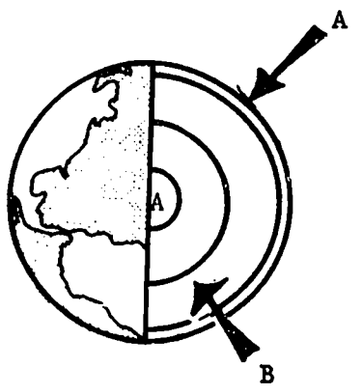


core (of the earth)

Concept non-examples include the following:

mantle (middle zone), crust (outer zone)

Pictorial non-examples:



A. crust
B. mantle

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: FOSSIL

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

> A fossil is any imprint or remain that is a clue (evidence) about plants and animals that lived long ago.

Supraordinate Concept(s): clue

Coordinate Concept(s): record, log, diary

Subordinate Concepts(s): imprint, remain, cast, mold

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Fossils:
1. are imprints or remains of plants or animals

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to fossil are those of its supraordinate, clue.

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of fossil include:
1. size: large, small
2. location (on the earth)
3. preservation medium (rock, ice, amber)

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Fossils can be formed from plants.

Concept examples include the following:

plant and animal fossils

Pictorial examples:

animal fossil

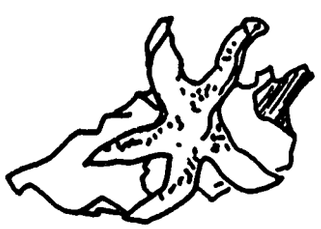
plant fossil

Concept non-examples include the following:

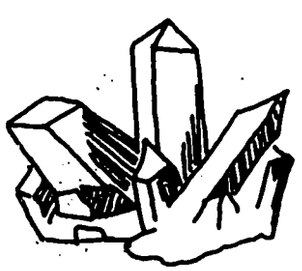
starfish, clam, insect, rock crystal

Pictorial non-examples:

insect (on leaf)



starfish



rock crystal

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: GLACIER

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A glacier is a force of erosion: a huge mass of packed ice and snow that moves slowly over the surface of the earth.

(Tested Definition: A glacier is a huge mass of packed ice and snow that moves slowly over the surface of the earth.)

Supraordinate Concept(s): force of erosion

Coordinate Concept(s): wind, water

Subordinate Concepts(s): valley glacier, continental glacier, mountain glacier

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Glaciers:

1. are huge masses of packed ice and snow
2. move slowly over the surface of the earth

The combination of the two attributes above is necessary to identify a glacier.

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to glacier are those of its supraordinate, force of erosion.

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of glacier include:

1. size
2. location on earth (latitude, longitude)
3. shape
4. speed of movement

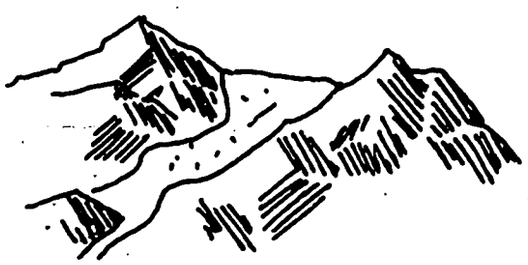
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

A valley can be caused by a glacier.

Concept examples include the following:

valley glacier, continental glacier

Pictorial example:

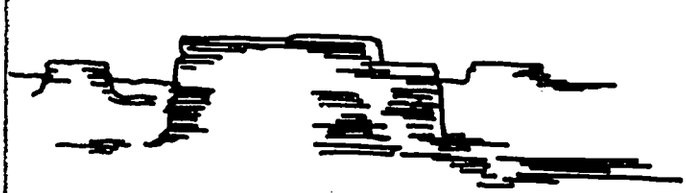


valley glacier

Concept non-examples include the following:

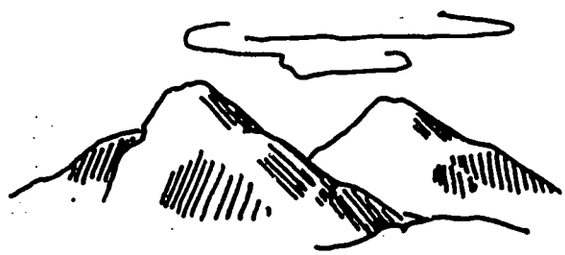
river, lake, butte, ocean, valley

Pictorial non-examples:



butte

river



mountain

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: METEOR

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A meteor is a meteoroid that enters the earth's atmosphere, and thus because of friction with the atmosphere, becomes hot enough to give off light.

(Tested Definition: A meteor is a piece of rock or metal which travels through space and which becomes hot and glows as it enters the earth's atmosphere.)

Supraordinate Concept(s): heavenly body

Coordinate Concept(s): moon, planet

Subordinate Concepts(s): stony meteor, metallic meteor

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Meteors:
1. get hot and glow as they enter the earth's atmosphere

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to meteor are those of its supra-ordinate, heavenly body, such as:
1. having their motion affected by other heavenly bodies
2. being located in space

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of meteor include:
1. location in space
2. composition
3. whether or not they reach the surface of the earth

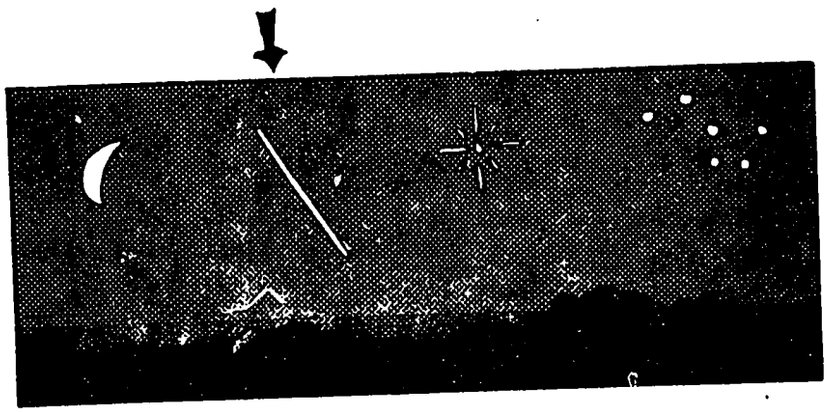
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Meteors can cause craters when they land on the earth.

Concept examples include the following:

meteor

Pictorial examples:

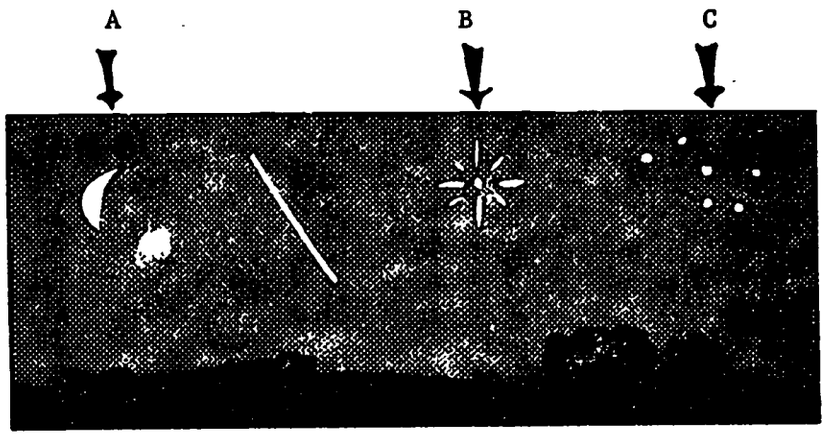


meteor

Concept non-examples include the following:

moon, star, constellation, sun

Pictorial non-examples:



A. moon B. star C. constellation

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: MOON

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A moon is a heavenly body which revolves around a planet and shines by reflected light.

Supraordinate Concept(s): heavenly body, solar system

Coordinate Concept(s): planet, meteor

Subordinate Concepts(s): natural moon, artificial moon

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

A moon:
1. revolves around a planet

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Relevant attributes of moon include:
1. shining by reflected light

Other attributes relevant to moon are those of its supra-ordinates, heavenly body and solar system, such as:
1. having a known path or orbit
2. being located in space
3. having their motion affected by other heavenly bodies

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of moon include:
1. size of moon
2. phase of moon
3. distance from planet

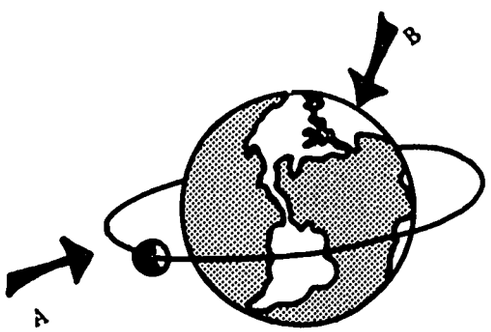
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

The moon can cause an eclipse of the sun.

Concept examples include the following:

moon

Pictorial examples:

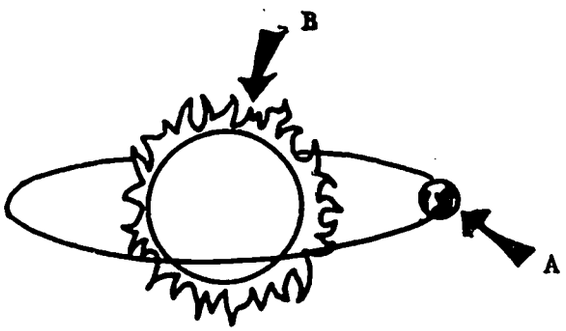


A. moon
B. planet (Earth)

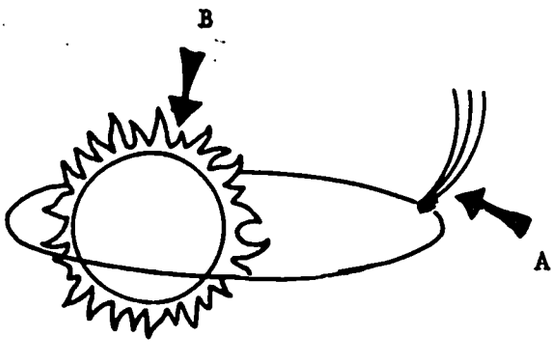
Concept non-examples include the following:

planet, meteor, sun, star, comet

Pictorial non-examples:



A. planet
B. sun



A. comet
B. sun

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: PLANET

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

A planet is a heavenly body which revolves around the sun and shines by reflected light.

Supraordinate Concept(s): heavenly body, solar system

Coordinate Concept(s): moon, meteor

Subordinate Concepts(s): major planet, minor planet

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Planets:
1. revolve around the sun

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Relevant attributes of planet include:
1. shining by reflected light

Other attributes relevant to planet are those of its supra-ordinates, heavenly body and solar system, such as:
1. being located in space
2. having their motion affected by other heavenly bodies

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of planet include:
1. visibility to the naked eye
2. temperature of the planet's surface
3. apparent color (to the earthly observer)
4. existence of life on planet

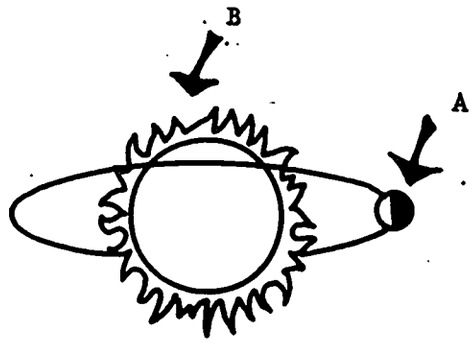
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Planets travel in paths called orbits.

Concept examples include the following:

planet

Pictorial examples:

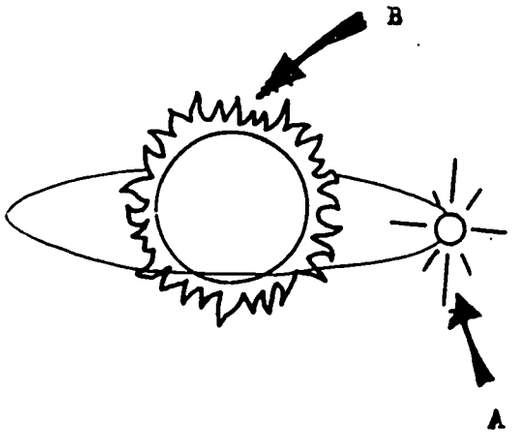


A. planet
B. sun

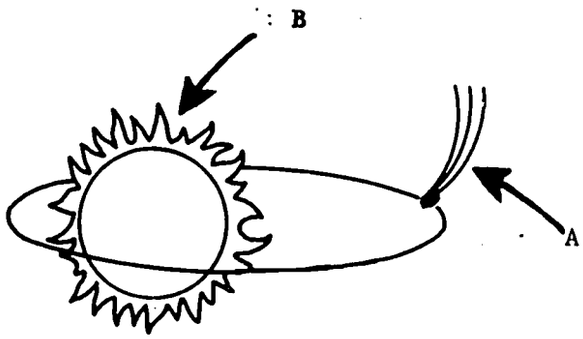
Concept non-examples include the following:

sun, star, meteor, comet, moon

Pictorial non-examples:



A. star
B. sun



A. comet
B. sun

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: SEDIMENTARY ROCK

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A sedimentary rock is formed in layers from sand, soil, and pieces of other materials.

Supraordinate Concept(s): rock

Coordinate Concept(s): igneous, metamorphic

Subordinate Concepts(s): limestone, sandstone, shale

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Sedimentary rocks are:
1. formed in layers

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to sedimentary rock are those of its supraordinate, rock, such as:
1. being a solid

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of rock include:
1. color
2. shape
3. surface sheen (shiny or dull)
4. texture
5. strength (tensile)

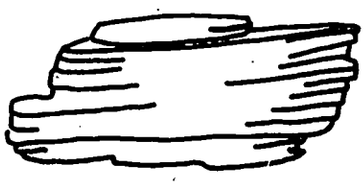
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Fossils are usually found in sedimentary rock.

Concept examples include the following:

sedimentary rock (limestone, sandstone, shale)

Pictorial examples:*



sedimentary rock

*Since it is difficult to depict kinds of sedimentary rock (e.g., limestone, sandstone, shale), with line drawings, only the generalized sedimentary rock is shown.

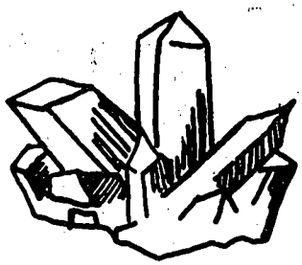
Concept non-examples include the following:

igneous rock, metamorphic rock, rock crystal

Pictorial non-examples:

igneous rock

metamorphic rock



rock crystal

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: VOLCANO

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

A volcano is a cone-shaped mountain formed by molten rock pushing up through a hole in the earth's crust.

Supraordinate Concept(s): mountain, landform

Coordinate Concept(s): hill, plateau, valley

Subordinate Concepts(s): active volcanoes, passive volcanoes, dead volcanoes

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Volcanoes:

1. are formed by molten rock pushing up through a hole in the earth's crust

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to volcano are those of its supra-ordinates, mountain and landform, such as

1. being landforms
2. protruding above the earth's surface

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of volcano include:

1. snow covered or not
2. color of surface
3. height
4. geographical location

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

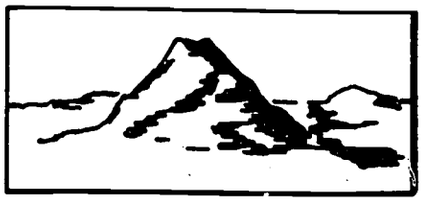
Igneous rocks are made of lava from volcanoes.

Concept examples include the following:

volcano

Pictorial examples:

volcano

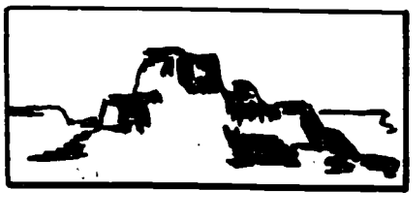


volcano

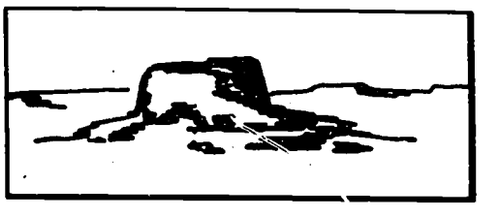
Concept non-examples include the following:

butte, rolling hills, plateau

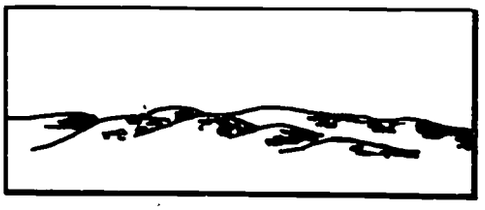
Pictorial non-examples:



butte



plateau



rolling hills

CONCEPT ANALYSES

Area: Earth Science

Target Concept Label: WIND

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

Wind is moving air caused by differences in air pressure.

Supraordinate Concept(s): force of erosion

Coordinate Concept(s): water, glacier

Subordinate Concepts(s): gale, hurricane, breeze

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Wind is:
1. moving air

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to wind are those of its supra-ordinate, force of erosion.

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of wind include:
1. location on earth
2. direction of movement
3. speed of movement

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Clouds are moved by wind.

Concept examples include the following:

leaves being blown around
a kite "flying"
trees "bending"
smoke leaving chimney at an angle

Pictorial examples:

a kite "flying"

trees "bending"

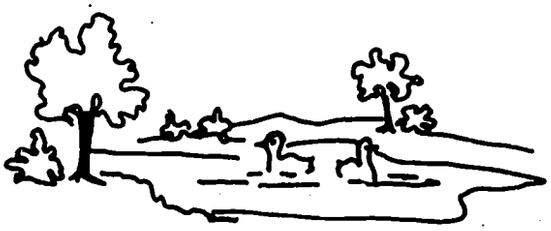
leaves being blown around

Concept non-examples include the following:

(These pictures indicate there is no wind blowing.)

flag drooping on pole
no ripples on a pond
smoke going straight up from a chimney

Pictorial non-examples:



no ripples on a pond

smoke going straight up from a chimney

flag drooping on pole

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: CONDUCTOR

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A conductor is a substance which lets energy flow through it.

Supraordinate Concept(s): matter, substance

Coordinate Concept(s): insulator

Subordinate Concepts(s): metals (wire, strips, etc.)

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

A conductor:

1. lets energy flow through it

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to conductor are those of its supraordinates, matter and substance, such as:

1. being made up of particles
2. possessing the properties of matter

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of conductor include:

1. size: e.g., large or small
2. shape: e.g., wire, strip, chunk
3. color: e.g., yellow, black, white
4. type of energy it conducts: e.g., heat, electricity

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

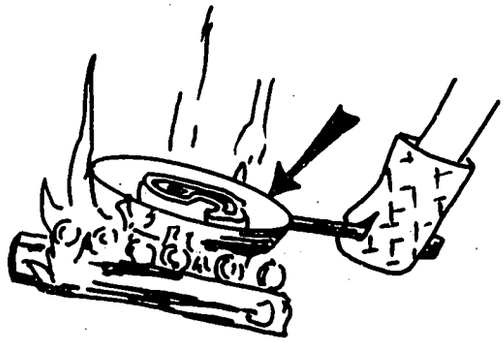
A conductor is needed to make a thermometer.

Concept examples include the following:

metal materials (hanger, pan, electric stove burner)

Pictorial examples:

metal hanger

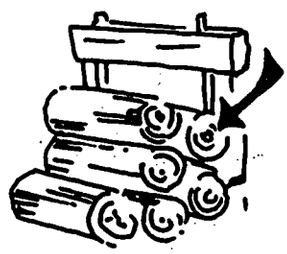


metal pan

Concept non-examples include the following:

wood, glass, plastic

Pictorial non-examples:



wood

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: EVAPORATION

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

> Evaporation is the process by which a liquid changes to a gas as particles escape from the surface of the liquid.

Supraordinate Concept(s): process

Coordinate Concept(s): condensation, melting, freezing

Subordinate Concepts(s): slow evaporation, rapid evaporation

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

In evaporation:
1. a liquid changes to a gas
2. particles escape from the surface of the liquid

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to evaporation are those of its supraordinate, process, such as:
1. involving molecular motion
2. involving energy

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of evaporation include:
1. speed of occurrence: e.g., slow, rapid
2. the color of the liquid

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

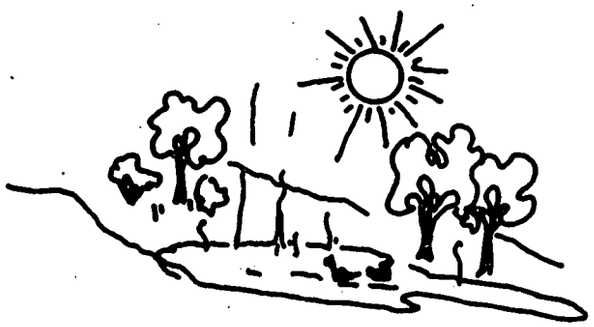
Evaporation can cause cooling.

Concept examples include the following:

evaporation caused by sun shining on the earth
steam escaping from a pan

Pictorial examples:

steam escaping from a pan



evaporation caused by sun shining
on the earth

Concept non-examples include the following:

condensation of water on the outside of a glass
snow storm
rain storm

Pictorial non-examples:

snow storm

rain storm

condensation of water on the outside of a glass

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: EXPANSION

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

Expansion is the process by which a substance increases in volume.

Supraordinate Concept(s): process

Coordinate Concept(s): contraction, condensation, evaporation, melting

Subordinate Concepts(s): volume expansion, linear expansion, area expansion

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

In expansion:

1. a substance increases in volume

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to expansion are those of its supra-ordinate, process, such as:

1. involving energy
2. involving particle motion

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of expansion include:

1. amount of increase in volume: e.g., small or large
2. speed of increase in volume: e.g., slow or rapid

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely <u>not</u> be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

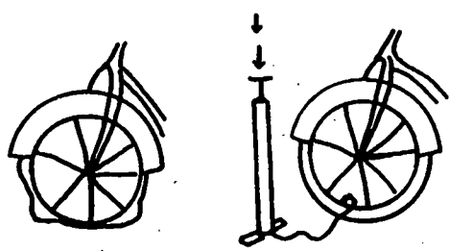
<u>Expansion</u> occurs when matter is <u>heated</u>.

Concept examples include the following:

blowing up of a balloon or bicycle tire
breaking a container (e.g. bottle breaks from water freezing in it)

Pictorial examples:

blowing up of a balloon

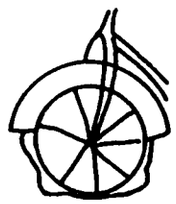


blowing up of a bicyle tire

Concept non-examples include the following:

a bicycle tire losing air
melting of a piece of butter
condensation of water on a glass
burning of a piece of paper

Pictorial non-examples:



a bicycle tire
losing air

melting of a piece
of butter

condensation of
water on a glass

burning of a piece
of paper

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: FRICTION

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

> Friction is the force at the surface (interface) of objects or materials which makes it hard to move them across or through each other.

Supraordinate Concept(s): force

Coordinate Concept(s): gravitational, electrostatic

Subordinate Concepts(s): sliding friction, rolling friction

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Friction:

1. occurs at the surface (interface) of objects or materials
2. makes it hard to move objects or materials across or through each other

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to friction are those of its supraordinate, force, such as:

1. involving energy
2. helping or hindering motion

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of friction include:

1. shape of the objects or materials
2. state of matter of the objects or materials

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Oxygen is necessary for friction to cause burning.

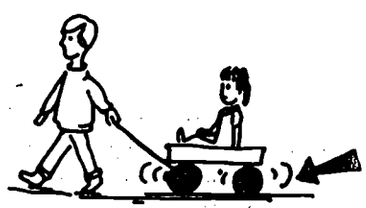
Concept examples include the following:

a sled rides over snow
a wagon is pulled along the sidewalk
a ball is thrown through the air

Pictorial examples:

a sled rides over snow

a ball is thrown through the air

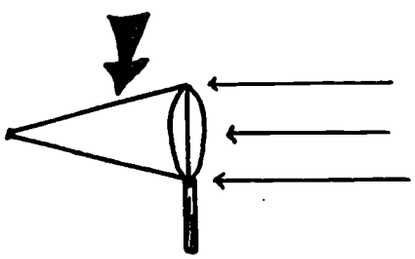


a wagon is pulled along the sidewalk

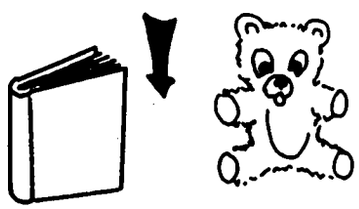
Concept non-examples include the following:

light passes through a lens
two objects are near but not touching or moving past each other

Pictorial non-examples:



light passes through a lens



two objects are near but not touching or moving past each other

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: LIQUID

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A liquid is a form of matter which has a definite volume and takes the shape of its container.

Supraordinate Concept(s): matter

Coordinate Concept(s): solid, gas

Subordinate Concepts(s): water, milk, gasoline

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

A liquid:

1. has a definite volume
2. takes the shape of its container

The combination of the two attributes above is necessary to identify a liquid.

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to liquid are those of its supraordinate, matter, such as:

1. being composed of particles
2. having weight
3. having volume

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of liquid include:

1. color
2. odor
3. viscosity

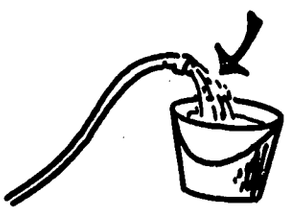
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

When a liquid changes to a gas it is called evaporation.

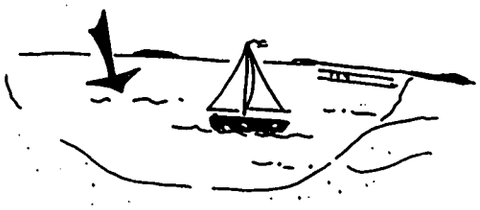
Concept examples include the following:

water, milk, honey, gasoline

Pictorial examples:*



liquid



liquid

liquid

liquid

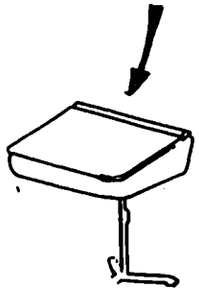
*Differentiation between kinds of liquid (e.g., between water and milk) is difficult with line drawings. Therefore, no attempt has been made to identify the pictorial examples other than as liquids.

Concept non-examples include the following:

all gases, all solids (i.e., rock, desk, top)

Pictorial non-examples: *

rock



desk

top

*Since gases are difficult to depict in line drawings, only examples of solids are shown.

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: MELTING

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

Melting is a process by which a solid changes to a liquid.

Supraordinate Concept(s): process

Coordinate Concept(s): evaporation, boiling, condensation

Subordinate Concepts(s): --

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

In melting:

1. a change in phase (form) occurs: solid changes to a liquid.

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to melting are those of its supraordinate, process, such as:

1. changing phase (form)
2. involving energy
3. involving particle motion

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of melting include:

1. speed at which it occurs: e.g., slow, rapid
2. kind of energy source: e.g., sun, stove, open fire

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

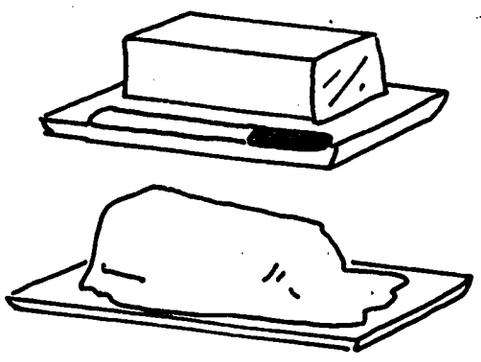
Matter changes from one phase (form) to another in melting.

Concept examples include the following:

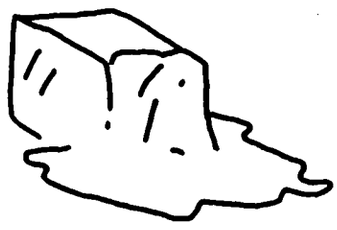
ice changing to water
ice cream changing from solid to liquid
snowman changing from a solid to liquid
butter changing from a solid to liquid

Pictorial examples:

ice cream changing from solid to liquid



butter changing from a solid to liquid



ice changing to water

snowman changing from a solid to a liquid

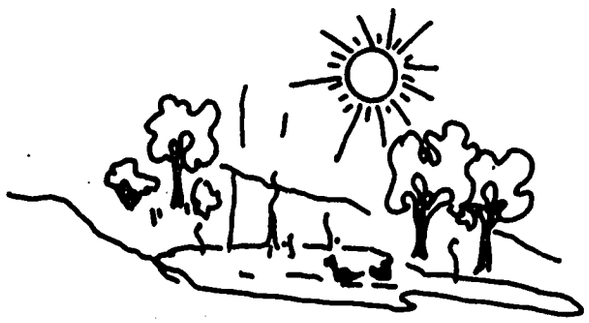
Concept non-examples include the following

evaporation, condensation, sublimation, boiling, freezing

Pictorial non-examples:

condensation

boiling



evaporation

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: MOLECULE

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supraordinate concept, then all attributes of the target concept should be given.)

A molecule is the smallest particle into which a substance can be divided and still keep all the properties of a substance.

Supraordinate Concept(s): matter

Coordinate Concept(s): --

Subordinate Concepts(s): large molecule, small molecule

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

A molecule is:

1. the smallest particle into which a substance can be divided and still keep all the properties of a substance

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to molecule are those of its supraordinate, matter, such as:

1. having constantly moving particles
2. having weight
3. taking up space

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of molecule(s) include:

1. color
2. taste
3. odor

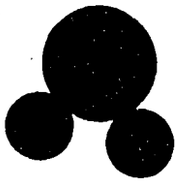
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supraordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Molecules are very close together in solids.

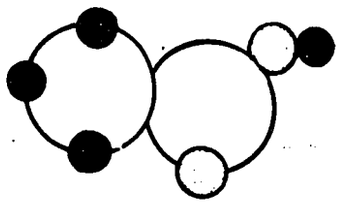
Concept examples include the following:

water, vinegar, carbon dioxide

Pictorial examples:



water

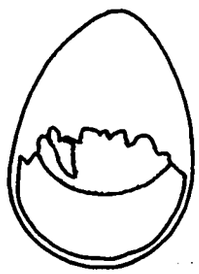


vinegar

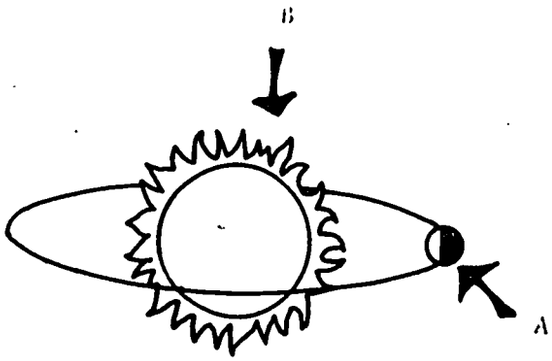
Concept non-examples include the following:

cell, planet, mixture, egg

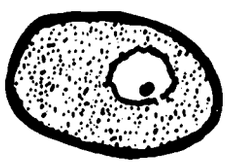
Pictorial non-examples



egg



A. planet
B. sun



cell

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: SOLID

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

A solid is a form of matter which has both a definite (exact) shape and a definite (exact) volume.

Supraordinate Concept(s): matter

Coordinate Concept(s): gas, liquid

Subordinate Concepts(s): table, rock, pan, chair

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Solids have:
1. a definite shape

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Relevant attributes of solid include:
1. having a definite volume

Other attributes relevant to solid are those of its supra-ordinate, matter, such as:
1. having weight
2. occupying space
3. being made up of particles which are always in motion

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of solid include:
1. color
2. size
3. texture
4. shape

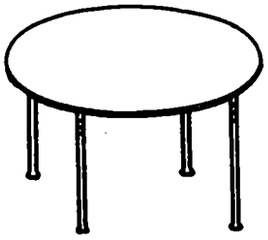
Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

When a solid changes to a liquid it is called melting.

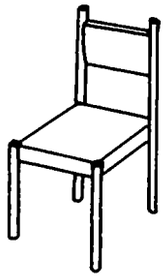
Concept examples include the following:

top, chair, table, rock

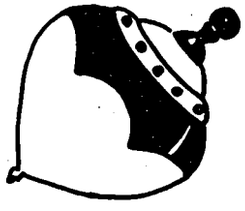
Pictorial examples:



table



chair



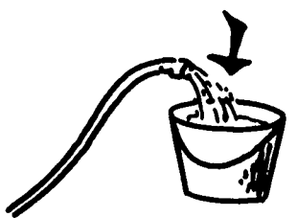
top

rock

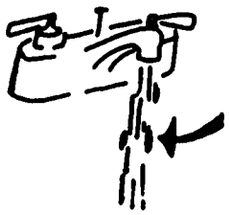
Concept non-examples include the following:

all liquids and all gases

Pictorial non-examples: *



liquid



liquid

liquid

*Since gases are difficult to depict in line drawings, only examples of liquids are shown.

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: SOUND

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

> Sound is a kind of energy which is caused by vibrations and travels only in matter.

Supraordinate Concept(s): energy

Coordinate Concept(s): heat, light, mechanical, electrical energy

Subordinate Concepts(s): loud sound, soft sound

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

Sound:
1. is caused by vibrations

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to sound are those of its supra-ordinate, energy, such as:
1. capable of being transmitted
2. capable of being transformed into other kinds of energy

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of sound include:
1. pitch: e.g., high or low
2. intensity: e.g., loud or soft
3. speed: e.g., slow or fast (depends on the kind of matter)

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

Sound does not travel in a vacuum.

Concept examples include the following:

a boy singing
someone playing a piano
clapping of hands
a boy beating a drum
plucking a guitar string

Pictorial examples:

a boy beating a drum

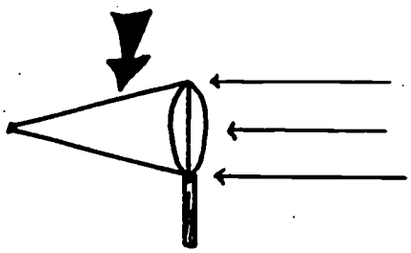
someone playing a piano

clapping of hands

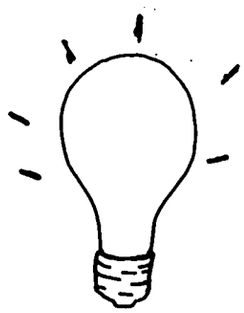
Concept non-examples include the following:

light being focused by a lens
heat energy being given off from a hot plate
light energy emanating from a light bulb

Pictorial non-examples:



light being focused by a lens



light energy emanating from a light bulb

CONCEPT ANALYSES

Area: Physical Science

Target Concept Label: THERMOMETER

Definition that gives the name of the supraordinate concept and the criterial attributes of the target concept. (If there is no supra-ordinate concept, then all attributes of the target concept should be given.)

A thermometer is an instrument used for measuring heat energy.

Supraordinate Concept(s): instrument

Coordinate Concept(s): barometer, radiometer, anemometer, voltmeter

Subordinate Concepts(s): mercury thermometer, air thermometer, water thermomete alcohol thermometer

Criterial attributes that differentiate the target concept from the supraordinate concept (or coordinate concepts if a supraordinate has not been identified).

A thermometer:
1. is used for measuring heat energy

Other attributes that are relevant but not criterial for the target concept. (The attributes of the supraordinate need not be specified.)

Other attributes relevant to thermometer are those of its supraordinate, instrument, such as:
1. having a calibrated scale of units

Irrelevant attributes of the target concept (attributes which vary among instances of the target concept) include the following:

Irrelevant attributes of thermometer include:
1. type of calibrated scale: e.g., Fahrenheit, Celsius, Kelvin
2. type of matter used in scale channel: e.g., alcohol, water, mercury, air
3. range of temperature to be measured: e.g., high, low

Relationship with at least one other concept. (This relationship should preferably be a principle. It should definitely not be a direct supra-ordinate-subordinate relationship, a relationship involving a criterial attribute, or a relationship involving an example.)

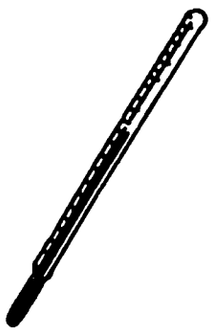
Expansion of the conducting material in a thermometer is due to an increase in temperature.

Concept examples include the following:

mercury, air, alcohol

Pictorial examples: *

thermometer



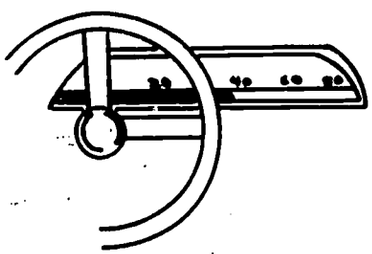
thermometer

*Differentiation between kinds of thermometer (e.g., between mercury, air, and alcohol) is difficult with line drawings. Therefore, no attempt has been made to identify the pictorial examples other than as thermometers.

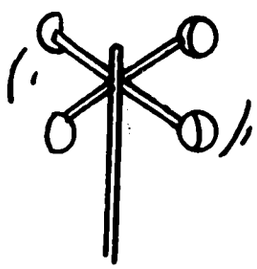
Concept non-examples include the following:

speedometer, barometer, anemometer, clock, voltmeter

Pictorial non-examples:



speedometer



anemometer